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TNO report Motorcycle power 74 kW study - Phase B

Abstract

For completion of the type approval of two- or three-wheeled motor vehicles, and in particular of Council Directive 95/l/EC of the European Community, the Directorate General III (Industry) commissioned a study to examine whether there is a relationship between motorcycle accident occurrence and motorcycle engine power exceeding 74 kW. The first phase of this study comprised a literature survey of existing studies, together with the factors that are likely to have a bearing on motorcycle accidents. This second phase consists of the following items:

1. Detailed arguments in order to demonstrate why a new study would not show statistically reliable relationship between engine power and the occurrence of accidents.

2. Recorded accidents and accident scenarios in which the engine power has or may have played a role will be described.

3. A comparison will be made of the power-to-weight ratio and acceleration potential of motorcycles and those of fast passenger cars and sports cars.

Arguments, which indicate that a new study will not show a relationship between motorcycle engine power and the occurrence of accidents

- The literature study has revealed that the major factors in accident risk are related to the motorcyclists (age, experience, attitude, alcohol, etc.), the accident circumstances (type and condition of the road, accident location, weather, etc.) and the exposure data (mileage, etc.). The list does not include any motorcycle performance property.

- The attitude of motorcyclists demonstrating risky riding behaviour, using the acceleration power frequently or riding very fast will not be changed if engine power is restricted to 74 kW.

- Less powerful motorcycles (street racers) still have higher acceleration power than motor cars.

- Information about motorcycle accidents are difficult to obtain. Each type of data source has its drawbacks. By combining sources, some of the drawbacks can be overcome.

Accidents in which engine power has or may have played a role

An inquiry among Dutch police accident investigators has shown that engine power can play a role in some types of accidents, but always in conjunction with other factors. The motorcycle accidents in which the engine power of the motorcycle can play a role can be characterised by the following situations:

- Pushing a motorcycle to the limits / reckless riding behaviour,

Causes: riders' attitude, riders' experience, engine power.

- Motorcycle not seen,

Causes: visibility, wrongly estimated speed. TNO report

- High acceleration,

Causes: riders' attitude, engine power.

- Running off the road in a bend,

Causes: misjudgement of situation, riders' experience, engine power.

- Anticipation of (sudden) changes in the traffic situation,

Causes: high speed, lack of concentration, riders' experience.

For most scenarios where the engine power has been or could been a factor there is no evidence that a restriction in engine power, to e.g. 74 kW, would have avoided the occurrence of the accident.

1. There is no evidence that the full engine power has been used in the development of the accident. It is not self-evident, that the used engine power exceeded the 74 kW boundary.

2. If accidents have occurred, in which the engine power had exceeded the 74 kW boundary, that does not implicate that the accident would have been avoided if less engine power had been available.

The accident investigators also indicate that an accident could in many cases have been avoided or have had less serious consequences if an emergency stop had been executed correctly by the motorcycle rider. Training motorcyclists specifically for emergency situations can improve the situation considerably. Technical modifications to the motorcycle braking system can lead to better vehicle control in emergency situations. These modifications include:

- A single control unit, instead of a separate front and rear braking system.
- Automatically controlled braking balance between front and rear brakes.
- Anti-lock system on front and rear brakes (ABS).

Power-to-weight ratio

In all scenarios where engine power has or may have contributed to the occurrence of an accident, the real factor is acceleration power (This holds for pushing to the limits, not seen and acceleration). Therefore, the relationship of engine power to, acceleration potential is further examined. A parameter, easy to be calculated, is the power-to-weight ratio. This is not identical with acceleration power, but can very well be used as an alternative.

A comparison of motorcycles and motor cars shows the superiority of common motorcycles, which have power-to-weight ratios of the same level as exotic super sports cars. Common motorcycles here mean motorcycles with engine powers of approximately 50/60 kW and/or engine sizes of 600-800 cc.

None of the other examined motorcycle engine properties (power [kW], size [cc] and torque [Nm]) have proven to provide a full alternative for the acceleration capacities of motorcycles, for they do not take all influences into account.

After power-to-weight ratio, engine power comes close but still leaves room for high acceleration capacities for light-weight motorcycles (and riders). A risk exists that 74 kW motorcycles will be constructed with extreme low weights introducing unnecessary stability or failure risks.

Contents

1 Introduction

For completion of the type approval of two- or three-wheeled motor vehicles, and in particular of Council Directive 95/l/EC of the European Community, the Directorate General III (Industry) commissioned a study to examine whether there is a relationship between motorcycle accident occurrence and motorcycle engine power exceeding 74 kW. The first phase of this study comprised a literature survey of existing studies, together with the factors that are likely to have a bearing on motorcycle accidents [I].

The conclusion of the literature survey is that there is no scientific evidence to suggest that engine size is a major factor in motorcycle accidents; engine size does not emerge as a risk factor. In statistical database studies, on the other hand, significant relationships were in fact found to exist, yet these studies failed to take the annual mileage into account, a measure of risk exposure for accidents and an influential factor.

Independent of the data source used, the studies indicate that, annually, more powerful motorcycles are involved in fatal and serious accidents than less powerful motorcycles. The high number of accidents involving powerful motorcycles is explained by the different pattern of use and the riders' characteristics.

The following main factors are found to be relevant in motorcycle accidents:

1. Age of the motorcyclist;

2. Experience of the motorcyclist;

3. Annual mileage.

Accident risk declines with both age and experience. Age and experience may be highly correlated, as most motorcyclists start to ride when young.

Based on the literature study of links between motorcycle accidents and motorcycle power exceeding 74 kW, a new study will have a very limited (theoretical) chance of finding any scientific and objective relationship/correlation between engine size, or power and motorcycle accidents.

The riders' age, experience, annual mileage and attitude, but also the situation at the accident site, the weather, etc., are some of the many other factors which influence the occurrence of motorcycle accidents. When measures are taken to reduce the maximum power of motorcycles, this will not result in a change of the riders' attitudes and driving behaviour, for example. The riders' attitudes and driving behaviour have a major influence on the occurrence of accidents. Powerful motorcycles are more involved in accidents. This difference with the light motorcycles originates from the drivers' attitude or the engine power, which are strongly correlated for specific types of motorcycles (e.g. street racers).

Besides, relatively lighter motorcycles, with an engine power just below 74 kW, have enough acceleration power (which means that the maximum velocity and acceleration are still excessive). This means, therefore, that the number of accidents will only be slightly influenced by engine power restrictions.

Summarised briefly:

1 Many factors determine the accident risk.

2 Drivers' attitude and the choice of a specific motorcycle and the engine power are correlated and hard or impossible to discriminate in a survey.

3 Restriction of engine power to 74 kW does not reduce the accident risk significantly, lightweight motorcycle have great potential for acceleration power.

Due to these arguments, no new study will be conducted in phase B. Instead, the study entails looking for arguments which indicate that motorcycle power or power-related factors can play a role in the occurrence of motorcycle accidents. These arguments will not be scientifically or statistical proven, but will give an indication in what way motorcycle power may be involved in the accidents or in the pre-accident phase.

The items which will be investigated in phase B are:

1 Detailed arguments in order to clearly demonstrate why a new study would not show any statistically reliable relationship between engine power and the occurrence of accidents.

2 Recorded accidents in which the engine power has or may have played a role will be clearly described. Distinctions will be made between accidents which are caused by the rider (skidding, braking out of a corner, etc.) and those in which the other traffic participants have difficulties estimating the speed and the approach of the motorcycle;

3 A comparison will be made of the power-to-weight ratio and acceleration potential of motorcycles and those of fast passenger cars and sports cars. The acceleration power of motorcycles will be quantified and compared to that of passenger cars.

The items referred to above are discussed in detail in Chapters 2, 3 and 4, respectively. The conclusions of phase B are presented in Chapter 5.

2 Arguments why engine power is not a factor in accident risk

This chapter presents arguments which indicate that a new study, according to the original phase B, will not show any statistically reliable relationship between engine power or power-related properties and the occurrence of motorcycle accidents (or one that a major influence on accident risk). In any new study, the engine properties should not be restricted to power only, but should also include the acceleration power. A reasonable choice of a characteristic value (or indication) for acceleration power is the power-to-weight ratio (engine power divided by the mass of the motorcycle and driver). Generally, the acceleration power increases with higher engine power and/or lower total vehicle mass.

Despite the fact that a new study can include more motorcycle properties, the chance on finding any reliable relationship between these motorcycle properties and the occurrence of accidents is expected to be very minor. Some of the reasons for this opinion are given in the following paragraphs.

2.1 Results of the literature study [1]

The data for motorcycle accident studies come from statistical databases of officially registered accidents, questionnaires/interviews among representative groups of motorcyclists or combination of the two. The studies reported numerous factors which influence the accident rate of motorcyclists. The influential factors are:

1. Age (or youth) of the motorcyclist.

2. Experience of the motorcyclist.

3. Annual mileage.

4. Attitude of the motorcyclist (normal, too fast, loss of control, adolescent risk-taking).

5. Type of road (built-up/non-built-up area).

6. Accident location (bend, junction).

7. Weather, including the condition of the road (dry, wet, icy).

8. Time of the accident (day/night, weekdays/weekend, season).

9. Alcohol.

10. Visibility (small frontal silhouette of the motorcycle).

These factors are related to the motorcyclists, the accident circumstances or exposure data. Many of these factors are highly correlated. However, none of these factors are machine properties such as the engine size, the engine power or power-to-weight ratio.

The above-mentioned accident rate is the risk of an accident occurring per travelled kilometre and not the accident rate per rider per year. The latter accident rate is more commonly used in statistical database studies, but more recent studies have taken the annual mileage as exposure data into account.

Whatever data source(s) any study has used, they commonly reported that powerful motorcycles are more frequently involved in accidents, but also have a different pattern of use in which annual mileage increases with engine size/power. The accident rate, weighted with the annual mileage, combines both effects which result in a diminishing influence of the engine size on the accident occurrence.

The most influential factors involved in motorcycle accident occurrence rate are the first three in the above list; age and experience of the rider and annual mileage.

Several major studies have reported that powerful motorcycles are involved more often in serious and fatal accidents. This phenomenon has been explained by the following circumstances:

1. Multiple vehicle accidents.

2. Accidents at night.

3. Accidents on bends.

4. Non-urban roads.

With respect to the last factor, the fatality rate on non-urban roads is higher and large motorcycles do ride more on these roads than light motorcycles.

The conclusion of the literature survey is that there is no scientific evidence that engine size is a major factor in motorcycle accidents; engine size does not emerge as a separate risk factor. Numerous studies in a number of countries around the world and over more than one decade have indicated that accident risk per distance travelled is not influenced by engine size, engine power or power-to-weight ratio.

However, some recent studies [3] have indicated that there might be a relationship between accident rate and type of motorcycle (tour, street, race, etc.), but this cannot be proven scientifically and statistically. These indications are based on a limited number of data.

2.2 Riding behaviour and attitude of the motorcyclist

The riding behaviour and the riders' attitude are more important factors with regard to the accident risk: Will the driver use the available engine power to go or accelerate very fast compared to passenger cars? It seems very likely that there is a relationship between the type of motorcycle and the riding behaviour and attitude of the rider. Touring machines are equipped for comfortable riding at constant cruising speeds and, therefore, the riders are not expected to race with them. Thus, for touring machines, the riders' attitude will correspond to the type of machine. A similar argument applies to racing machines, but with different and opposite results; the riders are more likely to use the power potential of their machine.

Motorcycle riders who often use the power potential of their racing machines and/or take risks will not change their attitude or riding behaviour when the maximum engine power for motorcycles is restricted by law. The question is whether a reduction in engine power to below 74 kW reduces the abilities of the motorcycle to such levels that risks are automatically reduced, independent of the riders' behaviour. Otherwise, a reduction of the number of accidents or a decrease of the accident rate could not be expected among this group of motorcyclists.

2.3 Motorcycle properties (power, etc.)

In general, motorcycle engine power is not likely to cause an accident. It is the application of this power by the motorcyclist which can be a factor in the "development" of an accident. Engine power can be used for high acceleration and/or speeds with respect to the situation on the road. Hence, engine power only plays a part in the pre-accident phase, the time phase before the actual crash or accident. This is particularly true when the accident involves speeding. With its high acceleration capacity, the motorcycle can reach speeds well above the limits at the road site (bends, crossings, traffic, etc.) in very short distances/times and at levels higher than other vehicles. The main causes of an accident in these circumstances are in fact speeding, risky behaviour, inexperience, etc. This is made possible by high engine powers but, again, the question is whether a limitation of the engine power to below 74 kW reduces these possibilities.

Secondly, the tyre is the part of the vehicle which transfers the engine torque to the road. If the grip of the tyre is too low for the driving force, the rear wheel will slip.

This can result in the motorcycle sliding or loss of control, which may give rise to a fall in which the injury severity of the motorcyclist is dependent on a numerous factors, such as speed, possible collision with an obstacle or other vehicle, road conditions, protective clothing, etc.

Powerful motorcycles have a higher acceleration rate and can reach higher maximum speeds than low-powered motorcycles. But even motorcycles with an engine power of 50/60 kW, for example, have a great potential with regard to acceleration power and reaching high speeds. On the other hand, engine power is not the only involved factor in these performance properties. The mass of the complete vehicle is also important. When comparing motorcycles with equal engine power and different masses, the lighter examples have higher acceleration power. Also, the faction potential and therefore the chance of provoking a wheel slip or spin increases with decreasing vehicle mass. Due to the fact that the weight of the rider is a major part of the total mass of the vehicle (values of 25% are common), the same argument is valid for light riders. In addition to the weight of the rider, his/her posture and sitting position has an effect on the actual acceleration and maximum speed due to the increasing air resistance at high speeds.

2.4 Active safety

Active safety of a road vehicle is determined by its handling and manoeuvring capacity. Good handling performance can make it possible for the driver to prevent a possible accident or collision. This means that motorcycle rider can take the necessary action by steering, braking and/or accelerating to stop in front of an object, to avoid an object or to escape from a dangerous situation. In these situations, control and stability of the motorcycle are crucial. Experience with evasive and braking manoeuvres is advantageous for the motorcycle rider in real situations, especially during an emergency braking manoeuvre, since a motorcycle only has two wheels and, if one or both wheels are locked, during the manoeuvre, a fall is unavoidable. A locked front wheel always results in a fall. That is why many riders do

not use the fully braking capacity of the front wheel brake, which results in longer braking distances and consequently a greater risk of accident.

2.5 Implications of new studies with respect to the data sources

The type of motorcycle accident data used can influence the ability to find, and the accuracy of, any relationship between engine size/power and motorcycle accident occurrence. Two different sources can be used; officially registered accident databases or questionnaires/interviews. Neither sources will produce a complete set of data regarding motorcycle accidents.

Officially registered accident databases:

1. Not all accidents are reported.

The number of officially registered accidents do not correspond to the real situation. Fewer than one in five is reported to the police in the United Kingdom according to Lynn [2]. The report rate varies with the severity level of the injuries and the size of the motorcycle. Accidents with large motorcycles and fatalities are more frequently reported than those with small motorcycles and minor injuries. But sometimes even fatal accidents are not reported.

2. Not all accident circumstances are reported and those which are reported may be incorrect.

3. Single vehicle accidents are not likely to be reported.

Questionnaires/interviews:

Special care must be taken when using questionnaires or interviews with respect to the following aspects, for they may bias the results:

1. The resulting data cannot be checked for it is not registered.

2. Only motorcyclists active during the inquiry phase of the research are questioned, so motorcyclists who have stopped riding motorcycles are not part of the study group (those riders were part of the motorcycle population for the studied time period).

3. The sample of motorcyclists must be representative of the active motorcyclist population. A well-designed sample of the group of riders must be taken to avoid this weakness.

4. Less information about fatal accidents. It is known that the fatality rate in accidents involving larger motorcycles is significantly higher than in those involving small motorcycles.

On the other hand, the advantages of questionnaires/interviews are:

1. Information about the experience of the rider (mileage, years, previous record).

2. Annual mileage.

3. More minor accidents will be reported, which are generally not registered, i.e. accidents with no or slight injuries, etc.

4. More single-vehicle accidents will be reported, etc.

5. Information about make, type, and other properties of the motorcycle.

A combination of both data sources will produce more and overall information about motorcycle accidents. But these sources cannot provide all the necessary information about each type of accident. The data can be improved when a new research expands both data sources, which will require:

1. Conducting an extensive survey in which a representative section of the active motorcycle population is asked for detailed information about the pattern of use, accident circumstances, etc.

2. Introducing a large-scale accident registration programme in which more data on all motorcycle accidents is registered by the police. This extensive set of data will have to be sufficient to achieve a better idea of the circumstances in which an accident happened and also to acquire more information about the vehicles (make, type, properties, condition, etc.) and persons (experience, annual mileage, etc.) involved. In addition, a representative number of the motorcycle accidents should be analysed in detail to determine how and why the accident occurred.

Such a new study, especially the detailed analysis of accidents, requires an extensive, long and very costly research project. There exist a strong correlation between the factors of motorcycles accidents. The riders' attitude and riding behaviour are correlated with the type of motorcycle he buys, and thus also with the engine performance properties. The result is that an unique relationship between a motorcycle performance property and the accident occurrence, not correlated with other factors (riders' attitude, riding behaviour, etc.), cannot be expected. Thus, no guarantee can be given that a relationship between engine size/power or power-to weight ratio and the occurrence of accidents can be proven statistically and scientifically.

Motorcycle population

The results (accident rate) are not only influences by the data sources but also by the motorcycle population used. The motorcycle population can comprise the number of licensed riders or the number of registered motorcycles. Neither will give the actual motorcycle population in the observed/analysed period, so care should be taken to determine the active motorcycle (cyclist) population. Another problem is the season- dependency of the active motorcycle population. More motorcyclist ride

more kilometres in the summer season than in the other seasons. During the winter, when the roads are covered with ice or snow, the active motorcycle population is very small. This means that motorcycle accidents should be analysed in detail over a period of at least one year to allow for the changing active motorcycle population and the different weather and road circumstances.

2.6 Conclusions

All arguments and implications given in the previous paragraphs indicate that for a new study to have the potential to establish a relationship between engine size/power or power-to-weight ratio and the occurrence of an accident, it will have to do the following:

1 . Analyse in detail a representative part of all motorcycles accidents over a period of at least one year.

2. Gather all the necessary of data on motorcycle accidents (circumstances, accident situation, data on vehicles and people involved, etc.) over a period of several years and in different countries from all available sources including questionnaires and interviews to obtain sufficient data and accidents to achieve reliable results.

3. Determine the active motorcycle population, which depends on season and time.

4. Take into account all factors which may have an influence in motorcycle accidents.

5. Define the accident rate as the ask for an accident per travelled distance.

6. Investigate whether other motorcycle performance properties than engine power can be significant as related to accident occurrence;

7. Determine all influential factors and their relationships to motorcycle accidents.

The main factors involved in motorcycle accidents are related to the motorcyclists (age, experience, attitude, alcohol, etc.), accident circumstances (road, bend, weather, visibility, etc.) and exposure data (mileage). Accidents in which engine power or acceleration power may be (partly) involved are more likely to be down to the riders' attitude and other circumstances than to the motorcycle performance properties.

Such an extensive study is very costly and nine-consuming and will Primarily improve the validity of the known influential factors in motorcycle accidents. Such a study is no guarantee at all that any relationship will be found between engine power or power related factors and accident occurrence discerned form effects like attitude. And lastly, short acceleration times and high maximum speeds cannot only be attributed to powerful motorcycles above 74 kW. Even motorcycles with for instance 50/60 kW engine powers can have relatively high values for acceleration and top speeds compared to the powerful ones and which are excessive in comparison to common sports cars.

3 Motorcycle accidents in which engine power might play a role

This chapter looks at motorcycle accidents in which engine power has or might have played a role. Using common knowledge about motorcycles and motorcycles accidents, a number of accident situations can be described in which engine power or any other power performance properties can play a role in accidents. The main information was gathered by means of a questionnaire sent to Dutch police accident investigators, who were asked for their opinions with respect to the influence of engine power on motorcycle accidents. The intention of the questionnaire was not to acquire objective statistics, but more directed to a subjective insight in the diversity of motorcycle accidents where engine power might be involved, i.e. the types of accidents, the characteristics of the motorcycles concerned and the main causes of the accidents.

The situations in which engine power or power-to-weight ratio might play a role, can be briefly given as follows:

I . Acceleration power o motorcycle appear suddenly for other traffic participants.

o driving at relatively high speeds on places where this is not expected.

9 general loss of vehicle control.

2. Top speed extreme speeds.

3. Loss of grip/ loss of vehicle control when driving away. wheel slip loss of vehicle control in bends as a result of acceleration.??!?

o wheels (front wheel loose contact with the road surface).

3.1 Questionnaire

The questionnaire was sent to all Dutch police accident investigators in the 26 police districts. The response of the accident investigators was very high, namely 80 percent.

The main gist of the questionnaire is to describe situations in which engine/-acceleration power plays a (indirect) role in the occurrence of an accident. If it does not, the investigators are asked to give other motorcycle properties which are of influence in accident occurrence. Another question is whether certain specific types of motorcycles are involved in accidents more often. Besides these main questions, the investigators are asked about their opinion on the trend in the number of motorcycle accidents and the proportion of powerful motorcycles involved during the last five years.

The next section discusses the number of accidents and the motorcycle types involved in them. The accident descriptions which, according to the police accident investigators, might be influenced by engine/acceleration power is discussed in section 3.3. The influence of the factors visibility and speed as well as braking and vehicle control are illustrated in sections 3.4 and3.5, respectively.

3.2 Number of accidents and types of motorcycles involved

Almost unanimous, the accident investigators of the Dutch police report that the number of motorcycle accidents has increased over the past five years. However, they all note that the motorcycle mileage has also increased, which means that the actual percentage of accidents not necessarily has changed. The percentage of accidents involving heavier motorcycles, i.e. motorcycles with engine powers over 74 kW (100 bhp), has not changed over the years either.

The most common type of motorcycles involved in motorcycle accidents turns out to be the street racer types with engine sizes over 600 cc. Remarkably, some investigators also reported that 'choppers' are relatively more involved in accidents as well. Choppers might have inadvertent handling aspects. However, since most drivers are male, in their forties, have just started riding motorcycle, etc., these accidents can also be related to inexperience in vehicle control.

3.3 Engine power related to accidents

Many experts know of accidents in which engine power may have played a role, but almost every example they give can also be ascribed to the attitude or riding behaviour of the motorcyclist. Higher engine power may lead to more serious accidents (higher speeds), but is not usually the direct cause of the accident. Few accidents occur at the maximum speed of the motorcycle. Many accidents occur due to riders over-estimating their capabilities. The combination of attitude, type of motorcycle and vehicle control experience were highly correlated in these accidents. Examples of power-related accidents are the 'single-vehicle' accidents, in which the motorcycle was pushed to the limit in terms of speed, acceleration and handling, and that limit was overstepped. This usually results in a fall (lack of vehicle control) and collisions with trees, traffic signs etc., aggravating the accident further. Restricting engine powers would lead to less accelerating capacities, but riders who like to ride on the edge will still do so. Examples of such accidents are:

ù Motorcyclists racing on public roads.

ù Motorcyclists pushing their vehicles to the limits on familiar (mostly winding) road sections.

* Motorcyclists showing off (doing wheelies, extreme accelerations etc.).

Other accidents in which engine power can play an indirect role are more related to vehicle control, riders' experience and judgement of situation. For example motorcyclists who are not familiar with the high power of their motorcycle can lose control of their vehicle. Most of these accidents occur in bends or winding road sections. Examples are:

Motorcyclists underestimating the quality of the road surface.
Motorcyclists breaking out of a bend because they are going too fast.
Motorcyclists accelerating too fast and losing control.

The majority of the accident investigators believe that a restriction of the maximum engine power or acceleration power will not lead to a reduction of motorcycle accidents, because the accidents are more related to the riders' attitude and vehicle control. They also note that the injury levels of the motorcyclists involved in accidents with heavier motorcycles are usually more serious and even fatal.

A description of accidents in which, according to the accident investigators, engine/acceleration power plays a role (be it directly or indirectly) are given in the following list. The order is not an indication of the significance of the engine power in the accidents described.

o Pushing to the limits / reckless riding behaviour

Site: winding road sections, mostly familiar to the rider.

Situation: rider pushes motorcycle too hard, and over-steps limit.

Involved: mostly solo drivers, sometimes small groups of motorcyclists

competing with another.

Type: the sportier, racier motorcycles.

Origin: rider-s' attitude, riders' experience, engine power.

o Motorcycle not seen

Site: junctions, built-up and non-built-up areas.

Situation: because of the particularly small frontal silhouette, the motorcycle is sometimes overlooked and the right-of-way rules are not applied correctly. This sometimes happens in combination with an underestimation of the motorcycle speed.

Involved: motorcycles and other motorists (motorcars).

Type: All types of motorcycles, no particular one.

Origin: visibility, wrongly estimated speed.

9 High accelerations

Site: mostly urban areas, near traffic light-controlled junctions.

Situation: a motorcycle is waiting for a traffic light. When the light turns green, the motorcyclist pulls away at high speed. Other participants in traffic do not expect the high speed with this short distance, and cannot anticipate.

Involved: the more powerful motorcycles, other participants in traffic (motorcars or pedestrians).

Type: the sportier and racier motorcycles.

Origin: riders' attitude, engine power.

o Running off the road in a bend

Site: long bends in the countryside.

Situation: a rider has entered a bend too fast to handle it. The motorcycle moves onto the wrong side of the road and runs off the road halfway through the bend or the rider loses control over his vehicle with the same results.

involved: more powerful motorcycles whose high power is more difficult to control.

Type: all types of motorcycles, high-powered motorcycles more frequently.

Origin: misjudgement of situation, riders' experience, engine power.

Anticipation of (sudden) changes in the traffic situation

Site: no specific areas; urban, countryside and highway.

Situation:

1) a motorcyclist sees a traffic jam or a traffic light too late and crashes into the vehicle in front of him. Many motorcyclist fall after executing an emergency stop incorrectly.

2) a motorcyclist rides at high speed on an unfamiliar straight road section, which is followed by an unexpected sharp bend. Sometimes the motorcyclist underestimates his own speed.

involved: motorcycle and sometimes other vehicles.

Type: all types of motorcycles.

Origin: high speed, lack of concentration, riders' experience.

The accident investigators also indicate other motorcycle properties which influence accident occurrence. 'These motorcycle properties are mainly visibility, braking control and vehicle control and are discussed in the next sections.

3.4 Visibility and velocity

One of the aspects which play an important role in the occurrence of accidents, is the limited visibility of motorcycles for other traffic participants. The frontal silhouette of motorcycles is particularly small, which makes it more difficult for other traffic participants to detect the motorcycle, or they only see it at the last moment. In multi-vehicle accidents at junctions, failure to detect a motorcycle is one of the major causes, and also one of the most serious ones. In addition to the late detection of motorcycles, underestimating their speed also plays an important role. The small silhouette of the motorcycle induces other traffic participants, who do not usually ride a motorcycle, to estimate the speed incorrectly. These speeds are often above the speed limits, which can be attained by any motorcycle, so high engine power is not required.

If a car driver overlooks a motorcycle at a junction, this will usually result in an emergency situation for both vehicles, and sometimes ends in a collision. In such collisions the fragility of the motorcyclists is evident, causing serious and often fatal injuries for the motorcyclists.

Another situation occurs in urban areas. There are examples of accidents caused by motorcycles accelerating quickly, reaching high speeds within short distance. Pedestrians crossing the street were hit by the accelerating motorcycle. This may be due to the pedestrians' overlooking the motorcycle or to the fact that they started crossing the street at the same time that the motorcyclist sprinted away from a traffic light. These accidents mainly occur with heavier race type motorcycles on road sections which invite riders to accelerate quickly. Although the number of this kind of accident might be reduced by restricting the maximum engine power of motorcycles, the riders' attitude is the dominant factor.

3.5 Braking and vehicle control

As we mentioned earlier, a majority of collisions in multi-vehicle accidents are preceded by an emergency stop. The behaviour of a braking motorcar is stable because of its four wheels, which is not the case for the two-wheeled motorcycles. A significant number of the accident investigators clearly state that many accidents could be avoided or at least have less serious consequences if the emergency stop were executed correctly. In many cases, the available brake potential is not used to the full or the motorcycle falls and slides forwards along on the road surface at a slightly lower speed. Higher impact speed in a collisions result in more serious injuries to the motorcyclists.

According to the accidents investigators, the number of accidents could be greatly reduced if motorcyclist brake correctly. They recommend that riders should receive more and better training in vehicle and braking control in emergency situations, either in the regular driving lessons or in special skill training courses. The main problem with braking of motorcycles is the dual braking system. The rearbrake is operated by a pedal (foot-operated), and the front brake is operated by a lever on the handlebar (hand-operated). In emergency situations, even experienced drivers can panic and brake incorrectly in a reflex action. In many cases, the motorcyclist involved is normally a car driver used to daily traffic, who in an emergency situation,

might only use the rear brake (foot), which considerably reduces the braking capacity of his motorcycle.

One way of improving the brake performance would be to modify the braking system. More than half (57%) of the accident investigators who responded suggest the following changes with respect to the standard braking system:

0 A single control unit, instead of a separate front and rear braking system.

0 Automatically controlled braking balance between front and rear brakes.

0 Anti-lock system on both front and rear brakes (ABS).

The above modifications will correct rider mistakes automatically and instantaneously, thus allowing better control of the motorcycle in emergency situations. This is not only advantageous for inexperienced torcyclists, but also for skilled riders.

3.6 Conclusions

Several accident scenarios are possible where engine power can play a role. All scenarios are a combination of motorcycle ability (availability of engine power) and riders' attitude. All scenarios can also be fulfilled with motorcycles with engine power below 74 kW.

According to the accident investigators of the Dutch police force, the number of motorcycle accidents has increased. However, due to a steady increase in the amount of motorcycle mileage, the accident rate per kilometre is not changed. The percentage of accidents involving heavier motorcycles has not increased significantly, but injuries are more serious.

Engine power may play a role, but only in combination with other aspects. The heavier racing motorcycles are involved in accidents more frequently, which often depends on the attitude of the rider. This type of motorcycles is more involved in single-vehicle accidents. The motorcyclist has been pushing the machine to the limits, racing with friends or showing off. Riders, who demonstrate this kind of behaviour would have the same attitude with less powerful motorcycles.

In some cases, control of the engine power is a problem. Inexperience with vehicle control can go hand in hand with a misjudgement of the situation. Accidents of this type occur in slow bends which a motorcyclist enters riding too fast.

One aspect which is always mentioned in multi-vehicle accidents is the visibility of a motorcycle. Because of the small frontal silhouette, motorcycles can easily be overlooked. At junctions, the right-of-way rules are not applied correctly because a motorcycle is overlooked.

The various kinds of accident situations in which engine power plays a role can be characterised by:

0 Pushing a vehicle to the limits / reckless riding behaviour.

Causes: riders' attitude, riders' experience, engine power.

0 Motorcycle not seen.

Causes: visibility, wrongly estimated speed.

0 High acceleration.

Causes: riders' attitude, engine power.

0 Running off the road in a bend.

Causes: misjudgement of the situation, riders' experience, engine power.

0 Lack of anticipation to (sudden) changes in the traffic situation.

Causes: high speed, lack of concentration, riders' experience.

Many multi-vehicle accidents at junctions precede by emergency stops. In many cases, an accident could have been avoided or be less serious if the emergency stop had been executed properly. This could be improved by training motorcyclists for emergency situations. Technical modifications of the motorcycle braking system would also help:

* A single control unit instead of a separate front and rear braking system.

ù Automatically controlled braking balance between front and rear brakes.

* Anti-lock system on front and rear brakes (ABS).

These modifications would correct rider mistakes automatically and instantaneously, thus allowing better control in emergency situations. This is not only advantageous for inexperienced motorcyclists, but also for skilled riders.

4 Power-to-weight ratio of motorcycles and sports cars

4.1 Introduction

Motorcycles, and especially powerful motorcycles, have acceleration capabilities which are superior to normal passenger cars. With the higher acceleration capacities, motorcycles can develop higher speeds within shorter spans of time and, hence, with shorter distances. Acceleration capabilities of motorcycles play a role in several accident scenarios. Therefore, a comparison was made between motorcycleís power of acceleration and that of motor cars and sports cars.

In this comparison, a broad variety of motorcycles have been selected. AU motorcycles chosen for the study (n=230) are new (1997) and available in the EU. Excluded from the extensive selection are custom-built bikes as well as motorcycles equipped with tuning sets to improve engine power/torque. All figures are based on models, they are not weighted for their portion in the active motorcycle population.

Different types of the following motorcycle manufacturers are used:

o Aprilia o Bimota o BMW o Buell o Cagiva 0 Muz o Ducati o Harley Davidson o Honda o Italjet o Laverda 0 Magni o Moto Guzzi * Kawasaki o Suzuki 9 Triumph o Yamaha

With respect to the motor cars, the top ten percent of each type of motor car, with respect to engine power, has been considered in this comparison. This top ten percent (n= 140) consists of the more sportive versions of common motor cars, with multi-valve or turbo-charged engines. In general, this means that GTi's and other over-powered cars of marks ranging from Alfa Romeo to Volvo are considered, including some exclusive powerful cars as BMW 750i, Mercedes 600, Rolls Royce and Bentley.

The top of the list consists of exotic sports cars, such as:

* Aston Martin o Caterham o Chevrolet Corvette * De Tomaso o Donkervoort o Ferrari * Lamborghini o Maserati o McLaren * Porsche o TVR

This selection of motor cars is made because it is well known that motorcycles have higher acceleration capacities than the average motor car, so only a comparison between motorcycles and relatively fast cars is of any use.

For comparison of vehicle acceleration capacities, this property first needs to be quantified. The characteristic value chosen for this purpose is the Power-to-Weight ratio, PtW:

Where:

0 PtW: Power-to-Weight ratio, [kW/ton].

0 PMax: Maximum engine power as given by the manufacturer, [kW].

0 mVehicle: Complete vehicle kerb mass as given by the manufacturer, [kg].

0 mDriver: Mass of the driver, [kgl. Chosen is a driver mass of 75 kg.

The driver mass chosen is equal to the value of ISO standard road test for evaluating the handling behaviour and road-holding capability of passenger cars. The Power-to-Weight ratio is not equal to acceleration itself, but gives a good indication of the vehicle's potential to accelerate.

The next section compares the Power-to-Weight ratios of motorcycles and fast motor cars. In section 4.3 other engine properties related to acceleration power win be discussed in an attempt to find better acceleration characteristic, which can also make distinctions between motorcycles of different natures (types).

4.2 Comparison Motorcycles and Motor cars

To compare the Power-to-Weight ratios of motorcycles and motor cars, the Power-to-Weight data has been plotted as a function of the engine power. With the engine power on the horizontal axis, two fan-shaped areas become visible in figure 1. Some markers are labelled with the name of the vehicle to give an indication of engine powers and Power-to-Weight ratio of particular motorcycles and cars. The lower fan (spotted triangles) represents the group of motor cars. The upper fan shows the PtW ratios for classified motorcycles. Note that even the average motorcycles have PtW ratios, which are only found in the exotic and extremely powerful sports cars. For both fans, the lower boundary is fanned by the more luxurious and comfort-oriented vehicles, i.e. touring bikes and limousines, respectively. The upper boundary is formed by the more sporty and race-oriented vehicles, i.e. the street racers and super sports cars, respectively.

Although Power-to-Weight ratios can be compared as an alternative for acceleration power, PtW value is not identical to acceleration power. However, a simple check of motor cars acceleration times for 0-100 km/h shows that cars with approximately equal PtW values have equal acceleration times. Also, higher PtW values lead to shorter acceleration tunes, but there is no linear relationship.

Figure 1: Power-to-Weight ratio as function of maximum Engine Power for Motorcycles and Motor cars.

On the basis of this acceleration check, we can compare motor cars mutually with respect to Power-to-Weight. We assume that such a mutual comparison is reliable for motorcycles too. But the weight and posture of the driver is of greater influence for motorcycles (mean 200 kg) than for motor cars (mean 1400 kg). Thus, acceleration data on motorcycles that exclude combined vehicle and driver mass is not always reliable. In addition to acceleration data, elasticity data (acceleration time for e.g. 80-120 km/h) can be compared with PtW-data. At this moment, not enough elasticity data on motorcycles is available. In tills case, as discussed before, the mass of the tested motorcycle (including rider) is of great importance. Because of the higher vehicle speed, the air resistance can not be neglected. A more aerodynamic posture of the rider leads to a lower air resistance, which leaves more power to accelerate. The posture of the car driver is of no importance.

To calculate the Power-to-Weight ratio, the complete vehicle kerb weight and the driver mass have to be taken into account.
When using the PtW ratio as an indication for acceleration power, the rotational inertia of gearbox, drive shafts, and wheels are neglected. Their influence on acceleration capability will not be very different for motorcycles or sports cars respectively. Therefore, PtW ratio of motorcycles shown in Figure 1 yield a fair comparison for acceleration capacity.

Comparing motorcycles with fast motor cars and sports cars

Both powerful motorcycles and a lot of medium powered motorcycles have high acceleration powers compared to fast motor cars. Figure 1 shows that motorcycles with engine power between 25 kW and 50 kW have PtW values equivalent to those of fast motor cars and even super sports cars. Only a few exotic super sports cars, like the Ferrari F50 and the McLaren Fl have higher PtW values. This is a reliable indication that motorcycles have superior acceleration capacities and depending on the actual maximum engine power, can reach high speeds in very short times and distances.

The PtW value as a criterion for legislation purposes has the advantage that motorcycles with more riding comfort (touring motorcycles) will not be assessed too strictly with respect to their engine power. The restriction has more impact for the street racers, which is the group of motorcycles for which such an acceleration restriction has more significance.

It is worth mentioning that powerful motorcycles are more common in road traffic than super sports cars, because they can be purchased for a fraction of the pace of a super sports car. This means that in normal traffic, the very fast and powerful vehicles are generally motorcycles, despite the fact that the motorcycle population is only a fraction of the total vehicle population.

4.3 Motorcycle qualities related to the Power-to-Weight ratio

The vehicle properties involved in the previous section are the vehicle weight and the engine power. This section relates various motorcycle properties to the Power-to-Weight ratio and shows the effects of possible restrictions of these properties and how they affect the different characteristics of motorcycles.

4.3.1 Maximum engine power

The characteristics of the maximum engine power as function of the Power-to-Weight ratio of motorcycles is presented in Figure 2. This figure is an enlarged part of Figure 1 and only looks at motorcycles.

Figure 2 shows a fan-shaped cloud of spots. The lower boundary is formed by the relatively heavyweight touring bikes. The upper boundary consists of lightweight street racers. Above the street racers is a special group of 2-stroke motorcycles. Because of the different engine principles, the specific power [kW/Litre] of 2-stroke engines is approximately two times higher than 4-stroke engines.

Restricting the maximum engine power at e.g. 74 kW does have a distinct effect on limiting acceleration powers, although the vehicle mass has not been taken into account. By using ultra-light vehicles, high Power-to-Weight ratios are still possible.

Figure 2: Power-to-Weight ratio as function of maximum Engine Power for Motorcycles.

The influence of the vehicle mass leads to PtW values of approximately 160 kW/ton for touring bikes, up to 300 kW/ton for street racers, and 2-stroke motorcycles can reach values of up to 350 kW/ton. Thus, a factor of two exists in the maximum Power-to-Weight ratio for different types of motorcycles. This means that a restriction in the maximum engine power will result in a strict limit for touring bikes and a less strict limit for (light) racing bikes on acceleration power.

4.3.2 Engine size

The engine size has a large influence on the maximum engine power and consequently also on the Power-to-Weight ratio.
However, as the following diagram (see Figure 3) shows, there is very limited correlation between engine size and Power-to-Weight ratios.

The most powerful (PtW) motorcycles have engines sizes from 600 cc up to 1200 cc with extremes around 1000 cc.
Restricting the engine size will not lead to a restriction in acceleration capacity.

Viewed horizontally: the largest engines are used for the so-called touring bikes, they are optimised for comfort by means of torque instead of maximum power. Also, these motorcycles are comparative heavyweights, so their Power-to-Weight ratios will not reach extreme values.

Viewed vertically: the variety that exist in engine power, as well as in vehicle mass leads to a range of a factor three in PtW ratio for 750 cc motorcycles, for example.

Figure 3: Power-to-Weight ratio as function of engine size for Motorcycles

Figure 4: Power-to-Weight ratio as function of engine Torque for Motorcycles

4.3.3 Maximum engine torque

Engine torque is closely related to engine size. We can estimate the engine torque of 4-stroke engines at 100 Nm per Litre to an accuracy of 20 percent. The torque of 2-stroke engines is approximately twice as high. For smaller engines the losses (heat and pressure) can be larger, so that the estimation is no longer accurate. Because of this relationship between engine size and torque, the following diagram (Figure 4) shows a great deal of similarity with the previous Figure (Figure 3).

For the same reasons as a restriction in engine size, a restriction in engine torque will not lead to lower acceleration capacities.

4.3.4 Power-to-weight ratio related to vehicle control (wheel spin)

The effects of the Power-to weight ratio on vehicle control can be represented in the maximum vehicle speed at which wheel spin can be generated. If wheel spin occurs, only riders' capabilities can prevent the eider from skidding. A simple calculation example can be made to obtain the approximate speeds:

Imagine a motorcycle accelerating fully, that means: at once a lot of power is released, and load due to the weight of the vehicle is transferred to the rear wheel. The following estimation can be made up to which speed a wheel spin can be generated:

Example: mvehicle = 300 [kg], motorcycle (225 [kg]) and rider (75 [kg]),

Pnw = 105 [kW], maximum engine power,

mfriction = 0.8, friction coefficient,

hpower = 0.8, efficiency ratio between maximum and effective power,

g = 10 [m/s2], gravitational acceleration,

Note that the Power-to-Weight ratio equals 350 [kW/ton].

Thus:

which corresponds to 126 km/h (multiplying with 3.6 to express in km/h instead of m/s).

The final equation is:

The first argument represents the Power-to-Weight ratio and the second argument can be approximated by 1/3. So, one can estimate the maximum speed at which wheel spin can be generated by:

nspin / PtW / 3 [km / h],

The accuracy mainly depends on the ratio between hpower and mfriction

The next table contains a selection of several, in this study, considered motorcycles. It shows the Power-to-Weight ratio and the estimated maximum speed at which wheel spin can be generated.

Table 1: Estimated maximum speed at which wheel spin can occur for several motorcycles

Table 1 shows that wheel spin due to engine power can occur up to considerable speed levels. For the 74 kW motorcycles wheel spin can occur in urban areas as wen as in the countryside. On the other hand, for the very powerful motorcycles wheel spins can occur at speeds well above the legal limits of the main roads (motorways included). Powerful motorcycles are disadvantageous with respect to vehicle safety with respect to this phenomenon.

4.4 Conclusions

The Power-to-Weight ratio has been introduced as a vehicle property to evaluate and compare acceleration capacities. The Power-to-Weight ratio is not acceleration itself, but gives an good indication of the acceleration potential. E.G., motor cars with approximately equal Power-to-Weight ratios show equal acceleration times for 0-100 km/h.

The comparison between motorcycles and motor cars shows the superiority of average motorcycles, which have the same Power-to-Weight ratios (PtW) as exotic super sports cars.

Installing a power limit at e.g. 74 kW will certainly remove the highest acceleration capacities. However, still motorcycles with very large acceleration power compared to super sports cars (e.g. Ferrari F50) will be available. Such power limits will put increasing pressure on weight reduction for certain categories of motorcycles. This can lead to adverse effects on vehicle stability and safety. Other measures, such as limitation of engine size or engine torque, does not lead to reduction in acceleration power.

Loss of vehicle control can appear when the rear wheel spins or slips due to use of excessive engine power. With a simplified calculation method, the maximum speed at which wheel spin occurs, can be determined with only the power-to-weight ratio of the motorcycle. Only very powerful motorcycles have the capability to achieve wheel slip above the legal speed limits on motorways. Even average motorcycles can have wheel spin within legal speed limits of roads in urban areas as well as the countryside.

5 Conclusions

New investigation

Within the motorcycle 74 kW study project, no new analysis has been conducted to investigate whether a relationship exists between engine size/power or power-to-weight ratio and the accident occurrence, because:

I . The literature study, the previous phase of the project, has revealed that there is no scientific evidence to assume that engine size is to be a major factor in motorcycle accidents; engine size does not emerge as a risk factor. The factors that are most influential in motorcycle accidents are related to the motorcyclists (age, experience, attitude, alcohol, etc.), the accident circumstances (type and condition of the road, accident location, weather, etc.) and the exposure data (mileage, etc.). This list does not include any motorcycle performance properties. The conclusions are based on numerous studies performed all over the world and covering a period of more than one decade.

2. Motorcyclists who use the power potential of their machines to tide or accelerate very fast, will not change their attitude or risky riding behaviour if the maximum engine power is restricted to 74 kW. Thus, with "lighter" motorcycles, a decrease of the accident rate among this group of motorcyclists is not to be expected.

3. Less powerful motorcycles (street racers), with engine powers of 50/60 kW, for instance, still have great potential with regard to acceleration power and reaching high speeds. This is because the mass of the motorcycle and rider, the transient behaviour of the engine (related to the type of motorcycle), the aerodynamic design of the motorcycle and posture of the rider (air resistance), speed (available power to accelerate), etc., also have an influence on the acceleration power. Accordingly, restriction of the engine power would result in a ban on types of motorcycles other than the racing types and motorcycles with less acceleration power (touring bikes).

4. It is difficult to gather all necessary information about the accidents, circumstances, vehicles and drivers. Each data source (official accident databases, questionnaires and interviews) lacks part of the data and/or accidents or the data is not completely reliable. In-depth investigation of motorcycle accidents and extensive surveys should be performed over a time period of several years. This because the pattern of use of motorcycles varies significantly over the time (day/night, weekdays/weekend) and seasons.

For these reasons, it is doubtful whether an extensive study would establish any relationship between engine power or any other motorcycle performance property and accident occurrence. On the other hand, it would improve the validity of known influential factors.

Accidents in which engine power has or may have played a role

An inquiry among Dutch police accident investigators has revealed that engine power can play a role in some types of accidents, but always in conjunction with other factors. The motorcycle accidents in which engine power of the motorcycle may play a role can be characterised by the following situations:

0 Pushing a motorcycle to the limit / reckless riding behaviour,
Causes: riders' attitude, riders' experience, engine power.

0 Motorcycle not seen,
Causes: visibility, wrong estimated speed.

0 High accelerations,
Causes: riders' attitude, engine power.

0 Running off the road in a bend,
Causes: misjudgement of situation, riders' experience, engine power.

0 Lack of anticipation of (sudden) changes in the traffic situation,
Causes: high speed, lack of concentration, riders' experience.

In some scenarios, the engine power may have played a role, but a restriction in engine power, to e.g. 74 kW, would have avoided an accident in very few circumstances:

I . In accidents, in which the engine power has played a role, not always the full engine power had been used in the development of an accident. It is not needed, that the used engine power exceeded the 74 kW boundary.

2. If accidents have occurred, in which the engine power had exceeded the 74 kW boundary, that does not implicate that the accident would have been avoided if less engine power had been available.

The accident investigators also indicate that an accident could in many cases have been avoided or have been less serious consequences if the emergency stop had been executed correctly by the motorcycle rider. Due to the lack of stability of the motorcycle and the rider' experience with emergency braking, it is not often the case that the full braking capacity of the motorcycle is used in an emergency stop. Training motorcyclists specifically for emergency situations can improve the situation considerably. Technical modifications of the motorcycle braking system can lead to better vehicle control in emergency situations. These modifications include:

0 A single control unit, instead of a separate front and rear braking system.

0 Automatically controlled braking balance between front and rear brakes.

0 Anti-lock system on front and rear brakes (ABS).

Power-to-weight ratio

Power-to-weight ratio is not identical with acceleration power, but can very well be used as an alternative. Tests of the acceleration tunes from 0-100 km/h in sports cars have shown similar results as the power-to-weight ratio, but the relationship is not linear.

A comparison of motorcycles and motor cars show the superiority of common motorcycles, which have power-to-weight ratios of the same level as exotic super sports cars. Common motorcycles here mean motorcycles with engine powers of approximately 50/60 kW and/or engine sizes of 600-800 cc. Common motorcycles can have high acceleration powers, but powerful engines are needed for high acceleration at high speeds or riding extremely fast (> 200 km/h, maximum speed is related to maximum engine power).

None of the other examined motorcycle engine properties (power [kW], size [cc] and torque [Nm]) has proven to be a full alternative for the acceleration capacities of motorcycles, for they do not take all influences into account. Of these factors, power [kW] comes closest but still allows for significant differences in acceleration power.

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